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Pricing Behavior in Partial Cartels

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Pricing Behavior in Partial Cartels

Johannes Odenkirchen*

September 2018

Abstract

We analyze the pricing behavior of firms when explicit partial cartels have formed in experimental markets through communication. Using a repeated, asymmetric capacity-constraint price game, we show that, in line with theory, a partial cartel is sufficient to increase market prices for all firms. Moreover, we find that prices of cartel insiders and outsiders are not necessarily on the same level what contradicts common theoretical predictions. This is because communication allows cartel members to overcome a potential coordination problem and enables an equilibrium in (joint) mixed strategies to emerge. The results therefore underline the importance of communication in explicit cartels and the resulting market outcomes.

JEL Classification: C92, D03, L13, L41.
Keywords: partial cartels, explicit collusion, umbrella effects, experiments

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1 Introduction

Cartels are a highly debated phenomenon in economic literature but little is known about partial cartels. Research that considers situations in which only a subset of firms in a market forms a cartel asserts that every firm in the market charges an increased price – even those who do not have explicitly agreed to anti-competitive behavior. This price increase of non-cartel members is linked to "umbrella effects" and is considered as inevitable (Blair and Maurer, 1982). More precisely, theory predicts the price of cartel insiders and outsiders to be equal (Inderst, Maier-Rigaud, and Schwalbe, 2014; Holler and Schinkel, 2017).

The models concerned with partial cartels merely consider cartel members as independent firms that tacitly coordinate on some focal price (e.g. the joint profit maximizing price). On the contrary, in real markets the most essential feature of hardcore cartels is arguably communication, which allows cartel members to group and coordinate.[1] This difference is important because communication can ultimately enlarge the set of equilibria (Athey and Bagwell, 2001; Balliet, 2010; Rahman, 2014; Awaya and Krishna, 2016) and might enable an equilibrium where prices are not on the same level.

We want to examine whether the standard predictions hold when we look at cartels in which cartel members can communicate with each other. More specifically, we want to examine the described umbrella effect and check whether prices of cartel insiders and outsiders are on the same level in an explicit partial cartel.

In order to get insights on this, we explore the actual pricing behavior of cartel insiders and outsiders in a laboratory experiment. The experimental setup is most helpful to gather information about the incentives in partial cartels as cartels are illegal and data on factors like communication is rare. An extensive empirical examination is therefore difficult to implement.

Our experimental design is based on a simplified version of the model by Bos and Harrington (2010) with price competition and heterogeneous capacity constraints in a dynamic setting, where a stable cartel exists. The capacities are chosen in a way that outsiders cannot compensate the intended effect of the cartel and the internal and external stability condition of partial cartels are fulfilled.[2]

The standard theoretical prediction in this model is that the largest firms in the

[1]For example, in EU competition law the burden of proof is reversed once communication between firms is proven. In this case, the involved firms have to prove that their communication had no effect on the market result whatsoever or will be charged for infringements of article 101 TFEU (European Commission, 2015).

[2]Partial cartels always base on restrictions such as switching costs, heterogeneous goods, heterogeneous marginal costs or heterogeneous capacities etc..

market form a cartel and choose the monopoly price for residual demand. This price serves as an umbrella for outsiders. The latter then free-ride by undercutting the cartel price by a minimal amount.

We argue that communication enables cartel members to deviate *jointly* from the monopoly price and to coordinate on different prices. The formation of the cartel is therefore very similar to a merger and virtually changes the capacity allocation. The ensuing equilibrium with regard to this argument is in mixed strategies and described by Hirata (2009) and De Francesco and Salvadori (2008). Equal prices occur here only by chance.

Supporting standard theory, we find that a partial cartel is sufficient to distort market prices. Average market prices are higher when partial cartels form than without any cartel in the market. This confirms the expected umbrella effect. However, we do not find average prices of cartel members and outsiders at the same level. Prices of outsiders are significantly lower than cartel members' prices on average.

This is because most of the observed cartel members play indeed some kind of *joint* mixed strategies in order to undercut outsiders, making it impossible for outsiders to adjust their prices optimally. The observed joint deviation is not possible without communication, as an unilateral price change of a cartel member could be interpreted as deviation from the cartel agreement result in a breakdown of the cartel. With communication, cartel members do not need to play pure strategies but can deviate jointly from the former cartel price and undercut only the outsiders to increase their profits. We further find that even if cartel members play pure strategies (as predicted by Bos and Harrington (2010)) and outsiders are potentially able to set their prices at the same level, they only do so after some periods and approach the standard equilibrium slowly, while average prices of outsiders are lower than cartel members' prices.

Importantly, we show that the price levels of cartel insiders and outsiders induced by umbrella effects can be very different. Cartel members can use more dynamic and sophisticated strategies by explicitly agreeing on different prices on short notice because they can communicate. Equal prices of cartel insiders and outsiders might therefore be more appropriate for tacit collusion where firms cannot directly coordinate on a price other than a focal point and have to stick to it once they manage to collude. This strong effect of communication is not considered by many models concerned with partial cartels and should be examined in further research here as well.

The remainder of this paper is structured as follows. We first summarize the related literature of this paper (Section 2). Then, we explain the model our experiment is based on and show the corresponding equilibrium (Section 3). In Section 4 we derive the equilibrium of a model that includes communication. Section 5 describes the experimental design and procedures. After listing our hypotheses in Section 6, we describe our results in great detail (Section 7) and discuss them with regard to economic theory. Section 8 offers a conclusion to our contribution.

2 Related literature

We connect several streams of literature. In the following section, we summarize the literature regarding partial cartels and illustrate the importance of communication for coordination and equilibria. Further, we discuss findings from the experimental industrial organization literature on explicit collusion.

The theoretical literature regarding partial cartels only focuses on cartel formation and stability where partial cartels are deemed as one possible outcome. The pricing behavior of cartel members and non-cartel members is consistently considered as a consequence of the formation process in the respective economic model that the cartel is scrutinized in. The explanation of the umbrella effect can be different depending on the model, but eventually all models predict equal prices between insiders and outsiders. In models of quantity competition, it is commonly assumed that when collusive firms reduce output, outsiders cannot compensate the entire reduction of supplied goods by the cartel due to increasing marginal costs of production. Therefore, the total supply decreases and prices increase accordingly, creating the aforementioned umbrella effect (Inderst et al., 2014; Holler and Schinkel, 2017). This causal connection has been shown in examinations of firms in Cournot models (Selten, 1973; Escrihuela-Villar, 2004) as well as Stackelberg models in both static (Shaffer, 1995) and dynamic settings (Martin, 1990; Konishi and Lin, 1999; Nocke, 1999; de Roos, 2004; Escrihuela-Villar, 2009; Zu, Zhang, and Wang, 2012).

Research on partial cartels in price competition also shows that the prices of cartel outsiders and cartel members are identical. Based on a static price leadership model as defined by Markham (1951), it was shown that cartel members anticipate the outsiders' reaction to a price increase and charge the monopoly price for the residual demand, also assuming increasing marginal costs of production (d'Aspremont, Jacquemin, Gabszewicz, and Weymark, 1983; Donsimoni, 1985; Donsimoni, Economides, and Polemarchakis, 1986; d'Aspremont and Gabszewicz, 1986; Daskin, 1989). Outsiders that are too small to influence the price take this price as given and produce until their price equals marginal costs (Blair and Maurer, 1982).

We do not rely on marginal costs in our model but enable partial cartels to emerge by restricting capacities of firms. Bos and Harrington (2010) determined equilibrium prices in a model of price competition with capacity constraints in a dynamic setting. The authors show that in this case the cartel price serves as an umbrella for outsiders who free-ride by undercutting the cartel price by a minimal amount without bearing the consequences - that is, reducing output.

None of the aforementioned models considers communication or distinguishes between explicit and tacit collusion. However, the market outcome can be very different if communication is available. Rahman (2014) shows that communication allows for more equilibria that would not be stable without communication. Awaya and Krishna (2016) show in their model an equilibrium with communication in which profits are strictly greater than in any equilibrium without communication. Models that explicitly investigate collusion and include communication show that it can help to coordinate and enables more stable equilibria (e.g. Athey and Bagwell (2001, 2008)). Harrington and Skrzypacz (2011) describe a model with communication which equilibrium fits recent detected cartels.

Communication not only enlarges the set of equilibria but also facilitates coordination and cooperation as shown by Crawford and Sobel (1982), Isaac and Walker (1988) and Farrell and Rabin (1996). Balliet (2010) illustrates that communication enhances cooperation in social dilemmas. Experiments by Cooper, DeJong, Forsythe, and Ross (1989, 1992) and Charness and Dufwenberg (2006) underline these findings. We use chat messages in our experiment, because free-form language is supposed to be most effective (Brosig, Weimann, and Ockenfels, 2003) to increase cooperation. It is also assumed that in this way subjects feel more secure about their decisions as participants can send messages to reassure each other and reduce uncertainty with regards to their decisions (Crawford, 1998).

The collusion facilitating effect of communication is well known and has been shown in industrial organization experiments many times (e.g. Andersson and Wengström (2007) or Cooper and Kühn (2014)). Fonseca and Normann (2012) focus on the different market outcomes between tacit and explicit collusion in an experiment when either all firms can communicate with each other or none. They find that the profit gains from communication are greatest for medium-sized markets. In these papers, communication only enhances collusion rates but does not enable a different equilibrium to emerge.

There is some experimental literature on partial cartels. This literature focuses on the formation process of partial cartels and antitrust policies however. Clemens and Rau (2013, 2014) examine a Cournot game where firms can decide on forming a partial cartel and outsiders automatically play their best-response, which corresponds to prices at the same level. Independent research by Gomez-Martinez (2016) examines the formation process of partial cartels and the coordinated effects of mergers within an extension of the Bos and Harrington (2010) model. In contrast to this work, we allow firms to communicate before every period at no costs and without agreeing to a cartel beforehand. We further restrict communication to firms that can form a stable partial cartel, thereby determining cartel members exogenously, since we focus on the pricing behavior in cartelized markets and not cartel formation.

3 Model

We use a model of an infinitely repeated capacity-constrained price game on the basis of the model by Bos and Harrington (2010). More precisely, we use an asymmetric Bertrand-Edgeworth market with $n = 4$ firms supplying a homogeneous good. Capacities are $k_1 = k_2 = 200$ (big firms) and $k_3 = k_4 = 50$ (small firms).[3]

Firms simultaneously and independently choose a price, p_i. They can select integers $\{0, 1, ..., 100\}$ for prices. We assume the firms' production costs up to capacity are zero for the sake of simplicity ($c = 0$). Upon reaching their capacity level, production costs are infinite. Demand $D(p)$ consists of $M = 300$ consumers who demand one unit of the good at minimal expense, as long as the price is not greater than $\bar{p} = 100$ and $D(p) = 0$ if $\bar{p} > 100$. Consumers are homogeneous and have the same valuation of the product. All firms have complete and perfect information.

Individual demand of firms $D_i(p_i, p_{-i})$ depends on their own price and the vector of prices of the other firms. Consumers buy from the firm with the lowest price first and buy from the firm with the next higher price only when supply of the firm with the lowest price is exhausted.

Capacities are allocated such that $\sum_{j \neq i} k_j \geq D(p) > k_i$. No firm has sufficient capacity to supply the entire demand and any subset of $n - 1$ firms can serve the entire market. Total capacity of all firms strictly exceeds total demand, $\sum k_i > D(p)$. This implies that not even the smallest firm sells a positive amount if it is the only firm that charges the highest price and on the other hand, even the largest firm sells at capacity if it solely charges the lowest price. We restrict the plethora of equilibria by a substantial assumption: if two or more firms charge the same price and therefore capacity exceeds demand at this price, demand is allocated proportional to each firm's capacity.

[3]Symmetries of large and small firms are chosen since symmetry can facilitate tacit collusion as shown in Fonseca and Normann (2008). The proportion of firms is chosen to be close to the findings of an empirical analysis by Harrington (2006) who found an average cartel size of around 75% market size for cartelized markets.

3.1 Static game equilibrium

The one-shot static Nash equilibrium in our model is the same as in a classic one-shot Bertrand game. Taking into account the decision making of the other firms, the best-response of each firm is to charge a price equal to marginal costs, that is, $p_i = 0$. A price higher than costs, $p_i > 0$, eliminates demand and yields no profit.

3.2 Infinitely-repeated game equilibrium

In an infinite repeated game, collusion is possible if firms are sufficiently patient, i.e. the discount factor δ is sufficiently low. More precisely, partial cartels can only arise if they fulfill the stability conditions defined by d'Aspremont et al. (1983) and earn higher profits than in the competitive equilibrium. Internal stability is given, since we assume firms to set prices according to the well known trigger strategy (Friedman, 1971), i.e., deviating from the cartel agreement would revert all firms to static Nash pricing at marginal cost for the reminder of the game, yielding profits of zero. Therefore, it is not profitable for a firm to leave the cartel and deviate from the cartel agreement. External stability is given due to the allocation rule. It is not profit-maximizing for an outsider to join the cartel and set the same price, because it would sell less output at a only a slightly higher price.

Insiders' prices

Let Γ denote the set of cartel members. When no communication between cartel members is possible, cartel insiders permanently set the collusive-value-maximizing price in equilibrium. Cartel members anticipate that outsiders firms will price below the cartel price. Therefore, they cannot sell at capacity when setting high collusive prices but will only serve residual demand. However, due to the insufficient capacities of the outsiders to satisfy the entire demand, they still face positive demand. Therefore, the actual behavior of outsiders is supposed to be not relevant for cartel members in the model. The cartel price is

$$p^{\Gamma} = p(K_{\Gamma}) = \operatorname{argmax} \left(\frac{1}{1-\delta}\right)(p-c)\left[\frac{D(p) - (\sum k_i - K_{\Gamma})}{K_{\Gamma}}\right]$$

With elastic demand the actual height of the price depends on the capacities under control of the cartel. In our model with inelastic demand, the monopoly price for residual demand simply is the reservation price,

$$p^{\Gamma} = \bar{p} = 100$$

A price higher than the reservation price, $p^{\Gamma} = \bar{p} > 100$, would result in a demand of zero, as no consumer is willing to pay more than the reservation price $\bar{p} = 100$. A lower price would merely lower profits but would not attract any more customers. Due to the distribution rule of demand, each cartel member's individual profit in each period is

$$\Pi_i^{\Gamma} = (\bar{p} - c) \left[D(\bar{p}) - \left(\sum_{j=1}^{n} k_j - \sum_{j \in \Gamma} k_j \right) \right] \left(\frac{k_i}{K_{\Gamma}} \right)$$

which is higher than competitive profits for any positive demand.

Outsiders' prices

The best-response of outsiders is to undercut the cartel price by a minimal amount ϵ, setting a price of

$$p_i^O = p^{\Gamma} - \epsilon$$

and sell at capacity to maximize their individual profit. Setting a lower price, $p_i^O < p^{\Gamma} - \epsilon$, generates less profit as the same output will be sold at a lower price. A higher price would reduce demand. Specifically, a price on the cartel level, $p_i^O = p^{\Gamma}$ forces the firm to reduce sales according to the proportional demand allocation rule. The marginal increase in price cannot compensate these losses in quantity. A price above the cartel price, $p_i^O > p^{\Gamma}$, results in no demand since cartel members can satisfy the entire demand at this price. Hence, no profit can be generated with this pricing strategy. The inflated price of the cartel can be used as an umbrella by cartel outsiders, who can free-ride by selling at a higher price without reducing their production. The consequential profits of each outsider in every period then amount to

$$\Pi_i^O = \left[(p^{\Gamma} - \epsilon) - c \right] k_i$$

4 Equilibrium with communication

Standard theory does not cover the possibility of cartel members to deviate jointly from an agreed price. Yet, communication and coordination are essential features of cartels. Since communication is available to firms in every period, we argue that firms do not have to choose necessarily the maximum price but can quickly coordinate on any price of the price range without costs. This joint deviation is not possible without communication, as an unilateral price change of a cartel member could be interpreted as deviation from the cartel agreement - which would most likely result in a breakdown of the cartel and consequently in Nash reversion. With communication, a price change can be announced or discussed, why cartel stability is not threatened. Therefore, we want to think of the cartel members as one merged firm which acts accordingly and consequently dominates the market due to its size. This feature virtually changes the capacity allocation and relation of demand to capacities to

$$K^{\Gamma} = \sum_{i \in \Gamma} k_i > D(p)$$

and

$$K^{O} = \sum_{i \notin \Gamma} k_i < D(p)$$

what implies $k_{i \notin \Gamma} < D(p)$. This constellation of asymmetric firms in Bertrand-Edgeworth markets, where only one firm can supply the entire demand and the remaining firms are minor players, is analyzed in great detail by De Francesco and Salvadori (2008) and Hirata (2009).

The equilibrium is then in mixed strategies. Firms set their respective price between a minimum and a maximum price. Cartel firms have to assess whether they want to act as a single monopolist for residual demand at a high price or lower their price in order to undercut outsiders and cover the entire demand. Cartel members cannot sell at capacity since their combined capacities exceed demand in any case, but they can sell a larger amount than residual demand by undercutting and serving the outsiders' former market share. This trade-off pays off until a minimum price of $\underline{p}$ is reached, at which the cartel, when serving the entire demand, would earn the same profit as selling residual demand at the maximum price. The minimum price of the cartel is therefore

$$\underline{p}^{\Gamma} = \bar{p} \cdot \frac{(D(p) - K^{O})}{min\{K^{\Gamma}, D(p)\}}$$

When cartel firms play mixed strategies, it is not rational for outsiders to play a pure strategy at their respective maximum price because of the cartels' capacities. Outsiders can only sell their supply if they choose a lower price than the cartel. The minimum price of each outsider depends on its own and the other firms' capacities. Calculating the minimum price of a non-cartel firm would give us

$$\underline{p}_i^O = \bar{p} \cdot \frac{\left(D(p) - (\sum_{j \neq i}^{n} k_j)\right)}{min\{k_i, D(p)\}}$$

Since $\sum_{j \neq i} k_j \geq D(p)$, this price would be $\underline{p}_i^O < 0$.[4] There is no residual demand outsiders could fall back to because the other firms can serve the entire market. Consequently, their reservation price and corresponding profits from residual demand would be 0 ECU. However, knowing that the cartel minimum price is $\underline{p}^\Gamma > 0$, a price below $\underline{p}^\Gamma$ is a non-credible threat by cartel members. Therefore, the minimum price of the outsiders should not be below

$$\underline{p}_i^O = \underline{p}^\Gamma - \epsilon$$

Since outsiders in our model are symmetric this holds for every outsider.

5 Experimental design and procedures

Subjects play the game as described in Section 3. In the treatment group, we allow for unmediated communication only between large firms of each group, thereby determining cartel members exogenously. Subjects can communicate in every period before they have to make their price decision for one minute in the first three periods of each supergame and for 30 seconds in the remaining periods of each supergame. This seems sufficiently long for the communication phase since previous experiments showed that most talk ended before the one-minute period was over (see for example Fonseca and Normann (2012)). Small firms just have to wait until the game continues. Subjects remain anonymous during the chat and are given neutral names like firm 1 or firm 2 which do not change during the session. Subjects are free to send as many messages as they like and to talk about what they want but have to respect two restrictions: Subjects are not allowed to identify themselves or post offensive messages. All subjects are aware that only the large firms can communicate with each other in each group and that only these firms can see the conversation. Subjects can not communicate with each other in the control group sessions and do not know about the possibility of communication in the other sessions.

All subjects receive written instructions which inform them about all the features of the experiment and the markets prior to the start of the experiment. A translated version

[4]The cartel capacity is already sufficient for that condition as $K^\Gamma \geq D(p)$.

for both groups can be found in the appendix (Appendix C). Once all subjects have read the instructions, they can privately ask questions. At the beginning of the experiment, all subjects are randomly assigned to one large firm or small firm and represent this firm for the entire experiment. In each period, before entering their payoff relevant price, subjects can use a profit calculator provided on the screen to test the potential impact of various own and other firm's decisions. In the following stage of each period subjects have to enter their price at a computer terminal. Once all subjects did this, the period ends and a screen displays the prices chosen by each firm in the market, the quantities sold by each firm and the profit of each individual firm in that particular period. Furthermore, the screen displays the accumulated profits of the respective firm (but not of the other firms) up to that point. Thereafter, the next period starts. We use a between subjects design for the experiment.

Participants are either in a control group or in a treatment group. Both treatments of the experiment respectively consist of three supergames that have multiple periods each to control for learning effects. Before each supergame subjects are randomly matched with three other firms so that there are two large firms and two small firms in each market. Throughout a supergame all subjects are matched with the same three other subjects in every period. Before each supergame all subjects are randomly assigned to a new group. The length of a supergame is determined by a random termination rule with a continuation probability of 8/9. This may be interpreted as an induced discount factor of $\delta = 0.88$, which is high enough for sustainable collusion according to the theory. All subjects are informed about the continuation probability. The actual numbers of periods per supergame are determined ex ante by a virtual die to ensure the same length of supergames over all markets, sessions and treatments. We have 144 participants in total. This is 72 participants per treatment divided into three sessions with 24 participants each. Hence, we are able to observe 18 markets per supergame per treatment or 54 markets per treatment respectively. Table 1 gives an overview of the design per treatment.

Subjects receive a payment consisting of a show-up fee of 5 Euro plus the sum of profits they earned during the experiment. The show-up fee is provided to moderate the expected asymmetric payoffs for subjects due to the differences in capacity of large and small firms. We use an "Experimental Currency Unit" (ECU) for payments, with 15,000 ECU being worth 1 Euro. The experiments were run in the Düsseldorf Institute for Competition Economics (DICE) Laboratory for Experimental Economics at the Heinrich-Heine-University Düsseldorf in July 2016. The experiment was programmed and conducted with the experiment software z-Tree (Fischbacher, 2007). Sessions lasted

	Supergame 1	Supergame 2	Supergame 3	Total
Periods	9	14	6	29
Markets	18	18	18	54
Participants	72	72	72	72

Table 1: Experimental Setup for each treatment

for approximately 60 minutes without communication and 80 minutes with communication. Subjects earned between 6 Euro and 26.50 Euro, with the average payment being 13.88 Euro. The online recruiting system ORSEE (Greiner, 2004) was used for recruitment, ensuring that subjects have not participated in similar experiments before. Subjects were students and non-students from a variety of backgrounds.

6 Hypotheses

We begin with the collusion facilitating effect of communication. In the experiment, big firms were not forced to establish cartels but could freely choose if they wanted to collude or not. Several experiments showed that communication has a pro collusive effect (as we described in Section 2), although communication should have no impact on firms behavior according to the extant literature. Fonseca and Normann (2012) showed that all firms in a market collude more frequently when all firms are able to communicate with each other. In our experimental setup, only 2 of 4 firms could communicate with each other in each market. Nevertheless, we expect these two firms to collude when communication is allowed, as the mechanics are identical and there is no obvious reason why communication should lose its impact when it is restricted to a subset of market participants, especially since there were no costs of communication and firms do not have to fear to be detected forming a cartel. Therefore, we expect that cartels form when communication is available.

Hypothesis 1. *When communication is allowed, cartels will form.*

Once we observe cartels, we expect cartel members to increase prices above the competitive level, as we have shown in our equilibrium analysis. Theory predicts that a partial cartel raising its price is sufficient to increase prices for the whole market independent of the cartels' respective pricing strategy. In our experiment with the underlying model, we expect small firms to recognize the price increase of cartel insiders, infer that a cartel has been formed and increase their prices, too.

Hypothesis 2. *When cartels form, prices of cartel insiders will be higher than in competition. Cartel outsiders follow and choose higher prices than in competition, too.*

The focus of our experiment is on the relation of cartel outsiders' prices to cartel insiders' prices. According to standard economic theory, cartels are expected to play pure strategies. In our experimental setting, the profit-maximizing price for a cartel is then the reservation price of consumers, $p^{\Gamma} = \bar{p} = 100$. Outsiders, pricing optimally by free-riding under the cartel's umbrella, should set a price at $p^{O} = \bar{p} - \epsilon$ in every period, independent of the actual price the cartel coordinates on. However, as we argue in Section 4, communication allows cartel members to play (joint) mixed strategies with prices between $\underline{p}^{\Gamma}$ and $\bar{p}^{\Gamma}$. Outsiders best response would be to play mixed strategies as well, randomizing their price p_i^O between $\underline{p}_i^O$ and $\bar{p}_i^O$. In this case, prices of insiders and outsiders would only be on the same level by chance.[5] Hence, we expect prices to be different.

Hypothesis 3. *Insiders' and outsiders' prices will not be on the same level.*

7 Results

In this section, we summarize our results and verify the hypothesis on the basis of the data obtained from the experiment. Our intention is to analyze the pricing behavior of firms in partially cartelized markets.

We do not analyze exactly the differences between our control group without communication and our treatment group with communication. Instead we focus on the differences between periods in which markets exhibit partial cartels and periods in which markets are characterized by competition to examine the umbrella effects. Hence, the definition of a cartel and competition respectively is crucial for our analysis. We further analyze the pricing behavior of cartel insiders and outsiders within markets that exhibit cartels to learn about the relation of their respective prices. Robustness checks where we compare solely the different treatment groups can be found in the appendix (B). The results presented hereafter do not change qualitatively when we do so.

Competition

We define firms to be in competition if communication is not available and firms do not choose equal prices higher than 1 ECU in two consecutive periods. The latter would be interpreted as tacit collusion but the definition allows for equal prices due to coincidence.

[5] Prices could be equal on average in the long run.

In fact, two or more firms chose the same price for more than one round simultaneously only in 2 of 54 markets or 14 of 522 periods, thereby exhibiting tacit collusion. All the periods of our control group without tacit collusion will be the benchmark for further analysis.

Partial cartels

We assume a cartel to be established only if communication was used and chosen prices of communicating firms were equal in subsequent periods. This is because communication between firms is legally considered as an essential characteristic of (hardcore) cartels and distinguishes tacit collusion from explicit collusion. We use an even tighter definition of a cartel and require an actual impact of communication to see that this was not only cheap talk.[6]

Cartels were established in 90.74% of the markets or in 80.27% of possible periods, respectively. Thereby we observe an learning effect over supergames with increasing rates of collusion (supergame 1: 72.22%, supergame 2: 82.54%, supergame 3: 87.04% of possible periods). These periods with active cartels will be the basis of our analysis of the price setting behavior in partial cartels. A deeper analysis of the periods without active cartels shows that some participants refused to use the chat and consequently did not set high prices. Our results show the power of communication once again and underline why the EU considers communication as important factor for collusion. Considering the data, our first qualitative result is in line with the previous literature and confirms hypothesis 1.

Result 1. *When communication is allowed, cartels form.*

7.1 Price levels and umbrella effects

In order to gain more information about the umbrella effect, we will next compare the price setting behavior of participants in our benchmark group (competition) and in cartelized markets. For a simpler analysis, we calculated the mean prices charged by firms with large capacity and the mean prices charged by firms with low capacity in each market for every period. This is reasonable since we are interested in the behavior of the two categories, potential cartel members and cartel outsiders. Furthermore, we

[6] Due to our approach, some periods in our treatment group are periods without established cartels, whereas there are no periods in our control group with active cartels by definition due to the lack of communication. On the other hand, some periods of our control group, where firms could not communicate but colluded tacitly, are not considered as periods with competition. This results in some periods not belonging to any of the two categories.

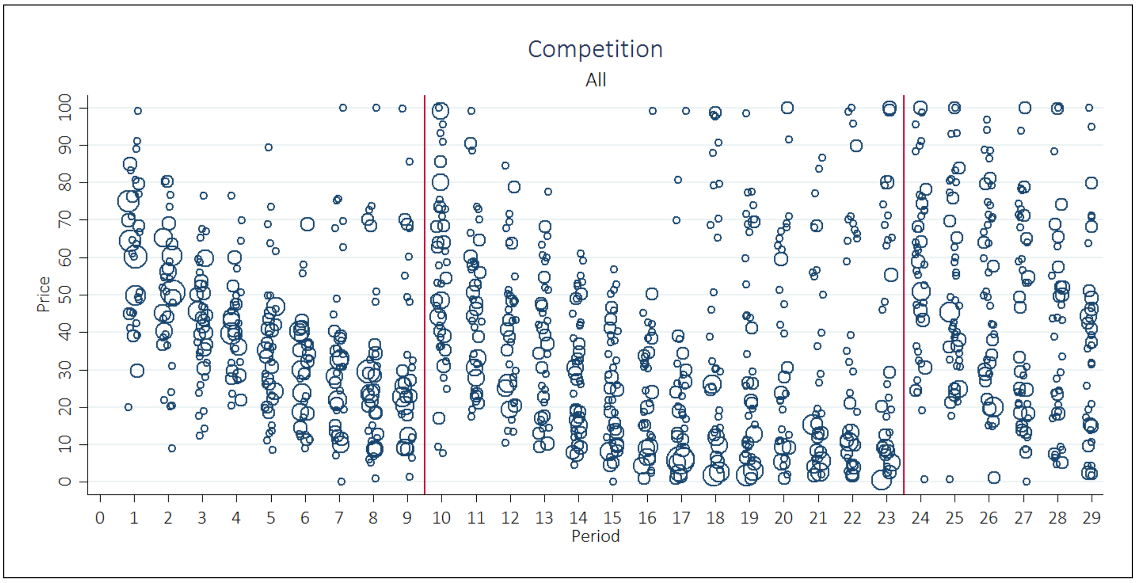

Figure 1: avg. chosen prices in ECU in competition
diameter of circle indicates price frequency

have to take into account that prices are not fully independent within the categories in our treatment group since we consider a cartel as established if both big firms choose equal prices. Therefore the average price is simply the price chosen by the cartel. Henceforth, we will call these proxies "BIGS" for the average price of firm 1 and firm 2 and "SMALLS" for the average price of firm 3 and firm 4.

7.1.1 Benchmark: pricing behavior in competition

We first evaluate our benchmark, that is prices chosen by participants in our control group when no tacit collusion occurred. Although we can observe fierce price competition, selling prices are not at the very end of the price scale but at a higher level. Participants chose from the full range of available prices $\{0, 1, ..., 100\}$ in their attempt to maximize profits. They ended up at an average selling price of 32.07 ECU. The average chosen price was 36.46 ECU (24.399 sd).

In this context, BIGS have an average selling price of 32.33 ECU and SMALLS have an average selling price of 31.83 ECU over all periods and groups when firms compete with each other. A Wilcoxon signed-rank test stating chosen prices of BIGS and SMALLS are equal cannot be rejected for each supergame ($p > 0.1$).[7] The distinct

[7] To be able to perform statistical tests, the tests were calculated with chosen prices, because outsiders cannot sell at a higher price than both big firms due to the capacity allocation.

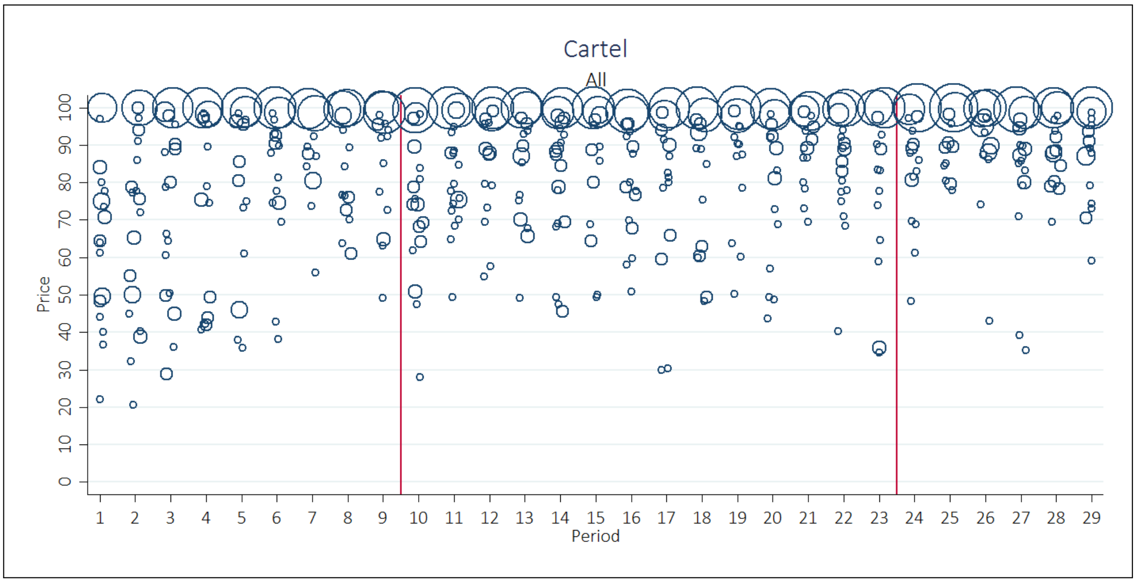

Figure 2: avg. chosen prices in ECU in cartel
diameter of circle indicates price frequency

groups showed different equilibrium prices. The average price level differs across groups between 9.54 ECU and 83 ECU. More precisely, BIGS average selling price was between 10.37 ECU and 75 ECU across groups, whereas SMALLS average selling price was between 8.11 ECU and 89 ECU across groups.[8] A Kruskal-Wallis test stating prices are equal across groups per supergame (same population) can not be rejected ($p = 0.4544$). Apparently, all groups show similar patterns of competition. Figure 1 illustrates the development of the average prices in competition and the equal price level of BIGS and SMALLS.

7.1.2 Pricing behavior in cartelized markets

In the next paragraphs, we look at the selling prices of participants representing BIGS in periods when they decided to form a cartel and compare them with the selling prices in competition (see also table 2).

Price level of cartel members

Prices of BIGS were higher when a cartel had been formed than prices of BIGS in competition in each supergame. A Mann-Whitney U test shows that prices of cartel

[8]The markets with high averages are two markets where tacit collusion occurred in earlier periods.

	avg. Price All (sd)	avg. Price BIGS (sd)	avg. Price SMALLS (sd)
competition	32.07 (21.438)	32.33 (20.525)	31.83 (22.315)
cartel	92.32 (14.429)	96.21 (10.604)	88.01 (16.710)

Table 2: average selling prices Competition/Cartel

members were statistically significantly different between a cartel situation and competition ($p = 0.0001$). This should be no surprise and supports common theory on cartel pricing. Overall, cartel members had an average selling price of 96.21 ECU (10.604 sd) when they coordinated on prices. However, we observe significant group differences. The average selling price of cartels was between 73.5 ECU and 100 ECU.[9] A Kruskal-Wallis test stating prices are equal across groups (same population) can be rejected at the 1% level ($p = 0.0001$). This indicates that cartels exhibited heterogenous price patterns across groups. We will discuss this later on in more detail. Nevertheless, our results are in line with common theory.

Result 2. *When partial cartels form, prices of cartel insiders are higher than in competition.*

Price level of cartel outsiders

Prices of SMALLS were significantly higher in a cartelized market than in a competitive market over all groups per supergame as well (Mann-Whitney U test, $p = 0.0001$). On average, selling prices of outsiders were at 88.01 ECU when a cartel was active (see also table 2). The aforementioned group differences are also observable for small firms. SMALLS average selling price was between 66 ECU and 99 ECU across groups. A Kruskal-Wallis test stating prices are equal across groups (same population) can be rejected at the 1% level ($p = 0.0001$). The different price levels observed for cartel members seem to be reflected in outsiders' prices. Considering our results so far, it seems obvious that once a cartel forms, prices of cartelists rise and outsiders follow. Figure 2 illustrates the average prices over all markets and firms per period with cartels.

Result 3. *When partial cartels form, prices of cartel outsiders are higher than in competition.*

Following from result 2 and result 3 we can confirm our hypothesis 2 and the common notion that when a cartel forms, the price level of the market rises overall, as we discussed

[9] In one market, big firms chose the same price only once and therefore had an average price of 45 ECU.

in the related literature. Further support is given by average selling prices over all groups and all firms, which were at 92.32 ECU. A Mann-Whitney U test shows that average selling prices of all firms combined were higher when a cartel was active than in markets with competing firms ($p = 0.0001$) for each supergame. The group differences in price levels (average prices between 68.75 to 99.5 ECU) can also be seen in these combined averages. A Kruskal-Wallis test stating prices are equal across groups (same population) can be rejected at the 1% level ($p = 0.0001$). Table 2 summarizes these results and leads to corollary 1.

Corollary 1. *A partial cartel is sufficient to raise prices above the competitive level for the entire market.*

7.2 The gap between insiders' prices and outsiders' prices

We now look at cartelized markets in more detail and compare our results with the equilibria of our model explained in Section 3 and Section 4.

We first notice, that cartel members did not always play pure strategies at the monopoly price but deviated from this price many times. The profit-maximizing price in pure strategies for a partial cartel is $p^{\Gamma} = \bar{p} = 100$. Over all markets, this price was chosen in 79.71% of possible times by cartel members. Considering descriptive statistics of the results in greater detail, we find that cartel behavior is quite heterogeneous. A deeper analysis of the price distribution reveals that the established cartels can roughly be categorized into two types. In 21 of the 49 cartelized markets cartel members played pure strategies and constantly chose the monopoly price of 100 ECU, i.e. in 100% of the possibilities. The average price of cartels in these markets is subsequently exactly 100 ECU. Cartels of this type (type 1) account for the majority of incidences where the monopoly price was chosen. Cartel firms of the other type (type 2) switched between many prices in the range between 37 ECU and 100 ECU. They played some kind if mixed strategies. The monopoly price of 100 ECU was chosen in 64.58% of the opportunities. Cartel members in these 28 markets account for all prices chosen by cartels which are below the monopoly price. The average price of cartels in these markets is 93.38 ECU.

Type-depending prices

We want to know whether prices of outsiders and insiders were on the same level depending on the cartel type. In our model, "same level" is defined as an outsider price equal to the cartel price minus a minimal amount, $p^O = p^{\Gamma} - \epsilon$, which is $p^O = p^{\Gamma} - 1$ in our experiment.

cartel price	both outsiders		at least one outsider	
p^Γ	$p^\Gamma \geq p^O \geq p^\Gamma - 1$	$p^\Gamma \geq p^O \geq p^\Gamma - 10$	$p^\Gamma \geq p^O \geq p^\Gamma - 1$	$p^\Gamma \geq p^O \geq p^\Gamma - 10$
cartel type 1				
$p^\Gamma = 100$	59.22%	72.63%	82.68%	88.27%
cartel type 2				
$p^\Gamma = 100$	19.35%	37.42%	45.81%	77.42%
$p^\Gamma \neq 100$	11.76%	18.82%	20.00%	41.18%
overall	16.67%	30.83%	36.67%	64.58%
pooled				
$p^\Gamma = 100$	40.72%	56.29%	65.57%	83.23%
$p^\Gamma \neq 100$	11.76%	18.82%	20.00%	41.18%
overall	34.84%	48.69%	56.32%	74.70%

Table 3: Price of Insiders and Outsiders

Outsiders in markets with a cartel of type 1 charged the second highest price (99 ECU) on average only in 69.55% of the cases when 100 ECU was chosen by the cartel in every period. Their average price was therefore 93.23 ECU. Table 3 also shows that SMALLS did not always choose their best response.

Outsiders in markets with a cartel of type 2 were only rarely in proximity of the cartel price. Outsiders' average prices in these markets is 84.41 ECU. A price of 99 ECU was only chosen 29.38% of the possible cases on average. A Wilcoxon signed-rank test stating that the average chosen price of SMALLS and BIGS are equal can be rejected for all type 1 and type 2 cartels separately ($p < 0.05$).[10]

Over all markets, the respective predicted price for outsiders of each period, $p^O = p^\Gamma - 1$[11], was chosen by both outsiders in only 34.84% of the cases. In 48.69% of the cases, both outsiders set a price in range of $p^O = p^\Gamma - 10$ to $p^O = p^\Gamma$. In 56.32% of the cases, at least one outsider charged the optimal price, $p^O = p^\Gamma - 1$ or the highest selling price $p^O = p^\Gamma$. In 74.70% of the cases, at least one outsider priced in close proximity to the cartel ($p^O = p^\Gamma - 10$) or set the same price as the cartel, $p^O = p^\Gamma$. A Wilcoxon signed-rank test stating that chosen prices of outsiders are on the optimal level ($p^O = p^\Gamma - 1$) can be rejected at the 1% level ($p < 0.01$) for each supergame.

The figures 5 and 6 in the appendix show the price patterns of the different types of cartels and the respective reaction by outsiders. In these plots we also see that cartels of type 2 do not randomize their prices perfectly but rather try to undercut outsiders

[10]To be able to perform statistical tests, the tests were calculated with chosen prices, because outsiders cannot sell at a higher price than a cartel due to capacity allocation.

[11]We also include here the highest selling price $p^O = p^\Gamma$.

systematically. Observing that outsiders use the cartel price as umbrella, cartel members have an incentive to deviate *jointly* from the former cartel price and charge a price just below the outsiders' price, since they serve only the residual demand when pricing higher than outsiders (e.g. at the maximum price, $\bar{p}$). Once the cartel notices that outsiders undercut the minimum price, it charges the maximum price $\bar{p}^{\Gamma}$ again and earn the maximum profit from residual demand, as we have shown in our equilibrium analysis for pure strategies. As soon as the outsiders adjust their prices and try to free-ride under the cartel's umbrella by setting $p^{O} = \bar{p}^{\Gamma} - \epsilon$, the cartel can undercut the outsiders again with $p^{\Gamma} = \bar{p} - 2\epsilon$ and the cycle starts again (compare Maskin and Tirole (1988)). In this case, prices can only be equal by coincidence. Hence, the hypothesis that outsider prices and cartel prices are not on the same level can be verified.

Result 4. *Prices of cartel outsiders and cartel insiders are not necessarily on the same level.*

8 Conclusion

In economic theory it seems undisputed that if partial cartels form, cartel members charge a higher price and enable outsiders to raise their prices, too. More precisely, outsiders' prices and cartel prices are supposed to be on the same elevated level (compare Blair and Maurer, 1982; Inderst et al., 2014; Holler and Schinkel, 2017). However, the standard models treat cartel insiders as two independent firms, even though hardcore cartels base on communication, which can enable a different equilibrium. We argue that communication allows for a equilibrium where prices of insiders and outsiders are not on the same level.

We examined explicitly the pricing behavior of cartel insiders and outsiders in partial cartels when cartel members can communicate with each other. Due to the secret nature of cartels, we used a laboratory experiment for this purpose. More specifically, we conducted a repeated capacity-constrained price game with asymmetric firms on the basis of the model by Bos and Harrington (2010), where participants could form partial cartels by communication via a chat tool.

We confirm the common notion that market prices are distorted when a partial cartel exists compared to a market without a cartel. Although cartels were incomplete, we find that every firm in the market charged a higher price, confirming the umbrella effect. This underlines the threat even partial cartels pose on consumers.

We do not find prices of cartel insiders and outsiders on the same level. We identified two cases of pricing strategies or types of cartels. In the first case, participants representing cartel firms constantly chose the same price on monopoly level. Outsiders played their best-response and followed the cartel price as predicted by Bos and Harrington (2010). They could maximize their profit by free-riding under the umbrella. Nevertheless, outsiders were reluctant to adjust their prices. It took multiple periods of constant cartel prices until outsiders approximated the cartel price. Therefore, prices of outsiders were statistically significantly different than insiders' prices.

In the second case, cartels did not constantly choose a single price. Instead, they deviated jointly from the former cartel price as soon as outsiders adjusted their price in order to receive the entire demand. Consequently, outsiders could not charge prices on the level of cartel insiders but had to choose lower prices to avoid being exploited. This joint deviation is only possible due to communication, which is not covered by standard theory. Considering cartel firms as a single big firm, the subsequent equilibrium with one dominant firm is described by Hirata (2009) or De Francesco and Salvadori (2008) and applies well to our data.

The results therefore show that prices of insiders and outsiders are not necessarily on the same level if we consider explicit cartels, where cartel members can communicate with each other.

It also shows the need for further research on explicit cartels. The market outcomes with explicit cartels might be different from market outcomes with tacit collusion also in other settings. Assuming that cartels do not face a coordination problem and behave like a merged firm, market characteristics that seemed to be crucial for collusion should be examined again. This however is beyond the scope of this study.

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Appendix

A Figures

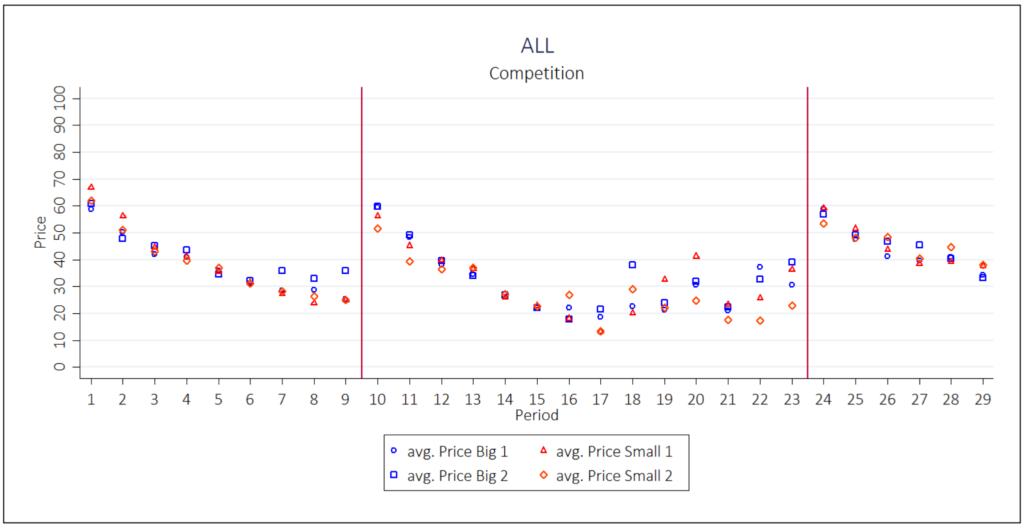

Figure 3: avg. chosen prices in ECU in competition

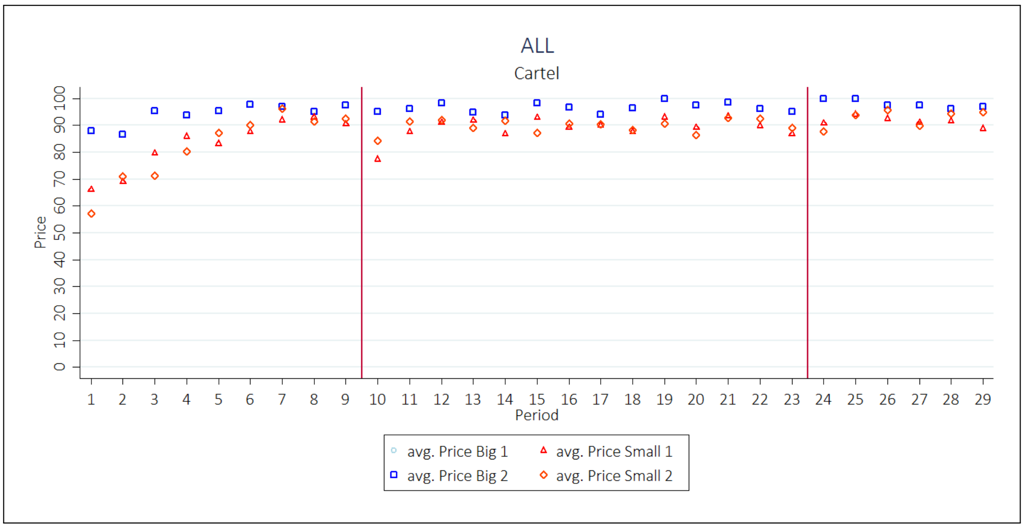

Figure 4: avg. chosen prices in ECU in cartel

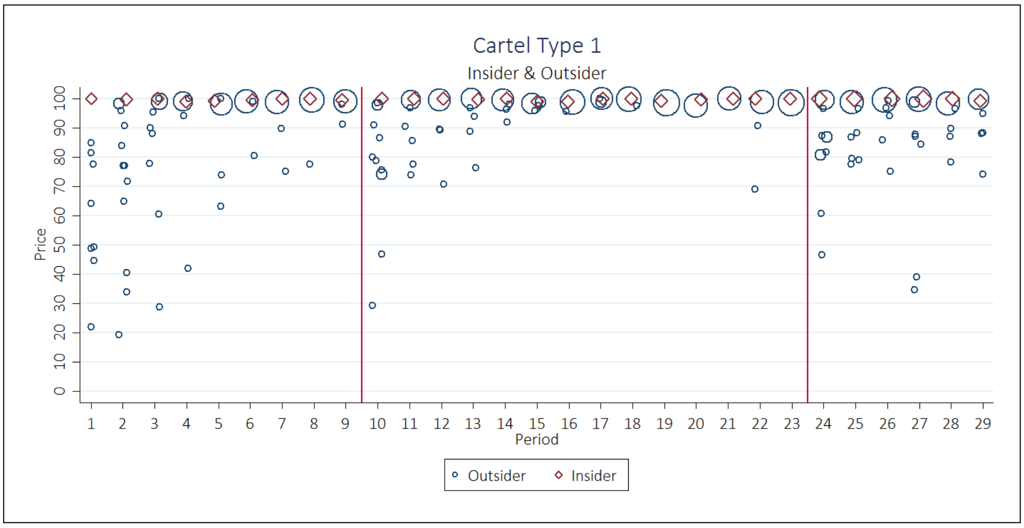

Figure 5: avg. chosen prices in ECU in cartel type 1

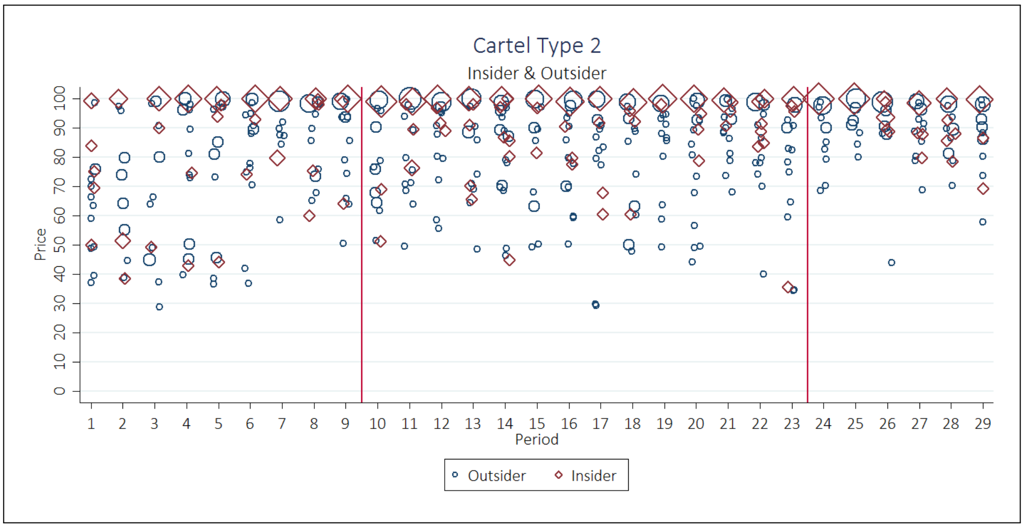

Figure 6: avg. chosen prices in ECU in cartel type 2

B Robustness Checks

Regression Analysis

Table 4: Price Regressions

	Chosen Price	Selling Price
Cartel	53.47***	37.82***
	(7.766)	(1.440)
big	1.394*	-0.00475
	(0.583)	(0.926)
Supergame	-5.748	-5.130
	(6.486)	(3.479)
Runde	-1.570	-1.471***
	(0.932)	(0.277)
Period	0.693	0.664**
	(0.489)	(0.308)
big=0 × Cartel=1	-6.641***	-8.151***
	(0.892)	(1.369)
Treatment		24.21***
		(1.272)
Constant	51.00***	42.49***
	(6.581)	(3.696)
Observations	4176	3483
Adjusted R^2	0.544	0.665

Standard errors in parentheses
cluster over session
* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Tables

Competition vs. Cartel

chosen prices

chosen	avg. Price All (sd)	avg. Price BIGS (sd)	avg. Price SMALLS (sd)
competition	36.46 (24.399)	37.13 (24.555)	35.80 (24.239)
cartel	92.19 (14.443)	96.21 (10.604)	88.18 (16.513)

Treatment 0 vs. Treatment 1

chosen prices

chosen	avg. Price All (sd)	avg. Price BIGS (sd)	avg. Price SMALLS (sd)
Treatment 0	37.76054 (26.91135)	38.63027 (27.52155)	36.8908 (26.27138)
Treatment 1	86.34339 (20.38314)	89.53257 (19.56247)	83.15421 (20.69521)

selling prices

selling	avg. Price All (sd)	avg. Price BIGS (sd)	avg. Price SMALLS (sd)
Treatment 0	33.97987 (25.16332)	34.35199 (24.90563)	33.59924 (25.43444)
Treatment 1	86.84469 (20.32311)	90.25685 (19.18873)	83.14317 (20.87463)

C Experimental Instructions

Instructions translated from German - for Control Group and Treatment Group - An additional part that was only shown to participants in the Treatment Group is italic

Hello and welcome to our experiment!

Please read this instruction set very carefully to the end.In this experiment you will repeatedly make decisions to earn money. How much you earn depends on your decisions and on the decisions of three other randomly assigned participants. Please do not talk to your neighbors and be quiet during the entire experiment. If you have a question, please raise your hand. We will then come to your booth and answer your question personally. All participants receive (and are currently reading) the same instructions. You will remain completely anonymous to us and to the other participants. We do not save any data in connection with your name. At the end of the experiment, you will get your profit paid in cash.

Market

In this experiment you will have to make decisions for one of four firms in a market. All four firms sell the same product and there are no costs of producing this good. This market is made up of 300 identical consumers, each of whom wants to purchase one unit of the good at the lowest price. The consumers will pay as much as 100 Experimental Currency Units (ECU) for a unit of the good.

Firm 1 and firm 2 are able to produce 200 units of the product and can supply an according number of consumers each. Firm 3 and firm 4 are able to produce 50 units of the product and can supply 50 consumers each. Your earnings are calculated as the product of your sold units and your selected price.

Distribution of consumers

In each period, all firms have to set their price, at which they want to offer their units. The firm who set the lowest price will sell its capacity at the selected price. All consumers who haven't bought a unit yet will then buy from the firm with the second lowest price. When there are still consumers left who haven't bought a unit yet, consumers buy from the firm with the next lowest price. If more than one firm set the same price and if the number of consumers firms can supply is higher than the number of consumers who haven't bought the good, they will split the available consumers proportionally to the firms' capacity. An example is given later. At the end of each period, all the firms are informed of the chosen prices by all firms in their group, the number of consumers each firm served (= sold units), profits of each firm and their own cumulated profits over all periods. For simulations of your potential profits, we will provide you with a "Profit Calculator", where you can check possible combinations of prices chosen by firms and the associated profits, prior to your price selection.

Communication ***(only for treatment group)***
Prior to your price decision, firm 1 and firm 2 will be able to communicate with each other in the market. For that purpose, we will provide participants representing these firms with a chat box, which can be used to send messages to the other person representing firm 1 or firm 2. If you are firm 3 or firm 4 you will not be able to communicate or read messages and just have to wait. Only firm 1 and firm 2 in each market will be able to see the sent messages. In the first 3 periods of each game firms are allowed to communicate for 60 seconds, in each additional period they have 30 seconds for this purpose. They are allowed to post how many messages they like and talk about what they like. There are only two restrictions on messages: they may not post messages which identify themselves (e.g. age, gender, location etc.) and they may not use offensive language. After the assigned time expires, the chat box will close and all firms will have to choose their price.

Groups
You will be randomly assigned to one of the firms at the beginning of the experiment and remain assigned to this firm for the entire experiment. The experiment is divided into 3 games, that have multiple periods each. Throughout a game you will be matched with the same three other firms in every period. However, you will be assigned to a new group before each game.

Duration
After every period, the computer will draw a ball of a virtual urn with 9 balls which are numbered from 1 to 9, to determine whether the experiment continues. If a value of 9 is shown, the experiment is over. If any other value is shown, the experiment continues. The ball is then returned to the urn. The odds of playing another periods is therefore ˜89% in each period. At the end of the experiment, which is after 3 games, you will be told of the sum of profits made during the experiment, which will be your payment. You

will receive 1 Euro for every 15,000 ECU you earn during the experiment. You will also receive 5 Euro for participating.

Examples

For a better understanding, two illustrative examples follow:

Example 1:

Suppose that the firms choose the following prices: Firm 1 sets a price of 85 ECU, firm 2 chooses a price of 100 ECU, firm 3 chooses a price of 75 ECU and firm 4 chooses a price of 95 ECU. Firm 3 set the lowest price and therefore faces a demand of 300 consumers. It has only capacity to produce 50 units. Therefore it sells all its 50 units at a price of 75 ECU, making a profit of 50 * 75 ECU = 3,750 ECU. Firm 1 has the second lowest price and will face a demand only of 300-50=250 consumers. Firm 1 has a capacity of 200 and can supply 200 consumers at its price of 85 ECU, therefore making a profit of 200 * 85 ECU = 17,000 ECU. Firm 4 has the lowest remaining price and sells all its 50 units at a price of 95 ECU making a profit of 50 * 95 ECU = 4,750 ECU. There is no consumer in the market left who has not bought a unit of the good, therefore firm 2 sell no units at its price and has profits of zero, 0 * 100 ECU =0 ECU.

Example 2:

Suppose that the firms choose the following prices: Firm 1 sets its price at 38 ECU. Firm 2 and firm 3 both set their price at 65 ECU. Firm 4 sets its price at 99 ECU. Firm 1 sets the lowest price. All 300 consumer want to buy its units. Therefore it can sell all its units and has a profit of 200 * 38 ECU = 7,600 ECU. Given that firm 2 and firm 3 set the same price and also given that their combined capacity (200+50=250 units) is larger than the number of consumers (300-200=100), they will have to share the available consumer according to their capacities. Firm 2 has a capacity of 200, firm 3 has a capacity of 50. Hence, firm 2 will sell 200/(200+50)*100 = 80 units at a price of 65 ECU, therefore making a profit of 80 * 65 ECU = 5,200 ECU. Firm 3 will sell 50/(200+50)*100 = 20 units at a price of 65 ECU making a profit of 20 * 65 ECU = 1,300 ECU. All consumers are satisfied. Firm 4 sells no unit at its price of 99 ECU and thus makes no profit (0 * 99 ECU = 0 ECU).

Good luck!

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